NOTE: Due to valuable feedback as a result of Proposers' Day, IARPA is reconsidering the technical focus of Phase 3. Proposers are therefore encouraged to read the upcoming BAA carefully and to note that there may be differences between the BAA and the information contained in this briefing (see slide 3).

*I*ntegrated *C*ognitive-Neuroscience *Ar*chitectures for *U*nderstanding *S*ensemaking

Proposers' Day
January 19, 2010

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Program Manager, Office of Incisive Analysis
Intelligence Advanced Research Projects Activity

Disclaimer

- This presentation is provided solely for information and planning purposes
- The Proposers' Day Conference does not constitute a formal solicitation for proposals or proposal abstracts
- Nothing said at the Proposers' Day changes requirements set forth in the BAA
- Any conflict between what is said at Proposers' Day and what is in a BAA will be resolved in favor of the BAA

No White Papers

- No white papers will be requested/accepted for ICArUS
- Proposals will be due approximately 45 days after the BAA is published
- Take advantage of this time to start developing your ideas

Outline

- Program Overview 
- Program Phases
- Program Metrics & Milestones
- Award Information
- Eligibility Information
- Application Review Information

Program Vision

ICArUS Program (5 yrs)

Goal: *Computational cognitive neuroscience* ***models*** *that explain, predict and emulate human* ***sensemaking***

Explain sensemaking based on underlying neuro-cognitive mechanisms

Predict human sensemaking performance, including cognitive biases & failure modes

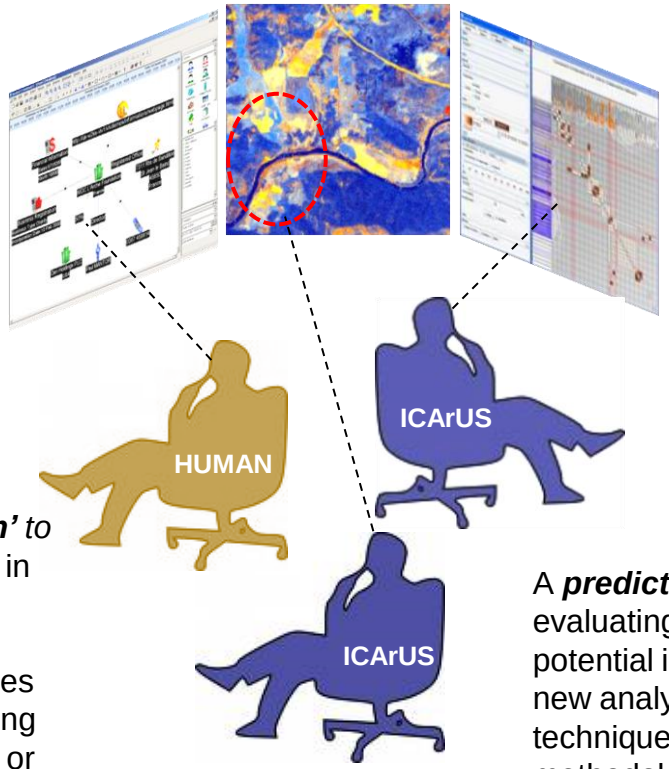
Emulate human sensemaking on complex analysis tasks

Transition

ICArUS Vision (5+ yrs)

Impact: *Incisive analysis* ***tools*** *for enhancing the performance of human-in-the-loop analysis systems*

An ***analytic force multiplier,*** taking over low-level sense-making tasks from over-burdened analysts



A generator of *"**insight models**"* for facilitating analyst intuition & discovery

A ***'mirror brain'*** *to* assist analysts in examining assumptions, identifying biases and re-examining underweighted or missed evidence

A ***predictive tool*** for evaluating the potential impact of new analytic techniques, tools & methodologies

Definitions & Assumptions

Sensemaking is the process of generating and evaluating hypotheses to explain data that is sparse, uncertain, and potentially deceptive.

"All individuals assimilate and evaluate information through the medium of…**'frames.'** These are experience-based constructs of assumptions and expectations both about the world in general and more specific problem domains."

– from *Tradecraft Review*. CIA Kent Center for Analytic Tradecraft

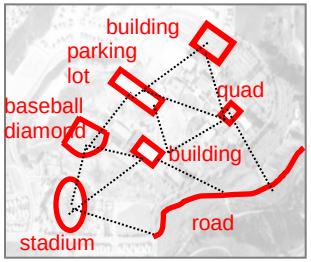
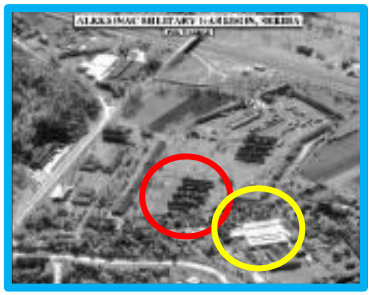
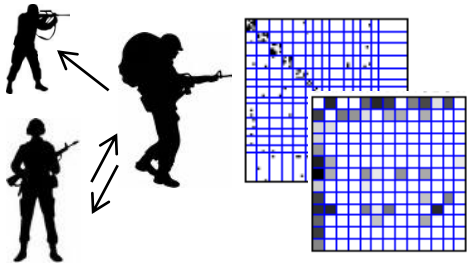
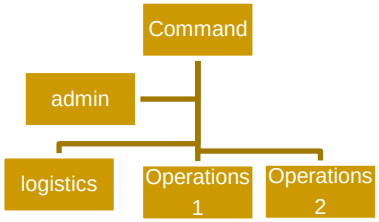
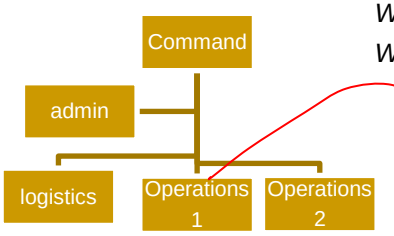
Sensemaking entails:

- Fitting one or more explanatory **frames** (mental models) to the **data**
- Actively *seeking* additional data to confirm or refute the current frame/hypothesis
- *Evaluating* the quality of the data
- *Deciding* whether to accept/reject the current frame
- Continuously *learning* new frames & modifying existing frames

ICArUS models must address <u>all</u> of the above functions

Sensemaking in Intelligence Analysis

Frames

	Observe data	Learn frame	Apply frame
Spatial Context	**Data:** Scenes, e.g. overhead images 	Typical scene contents & geometry 	 *What type of facility is this?* *What is the function of these buildings?* *What is stored in this structure?*
Relational network	**Data:** Actors & interactions 	Organization / command structure 	 *What is his operational role?* *Who does he report to?*  *What valuable info might he have?*
Script	 t_0 t_1 t_2 t_3  **Data:** Ordered events	t_0 Unload object t_1 Dig and bury object t_2 Lay wire t_3 Depart scene	  *What is happening here?* *What will happen next?* *What is the ultimate outcome?*

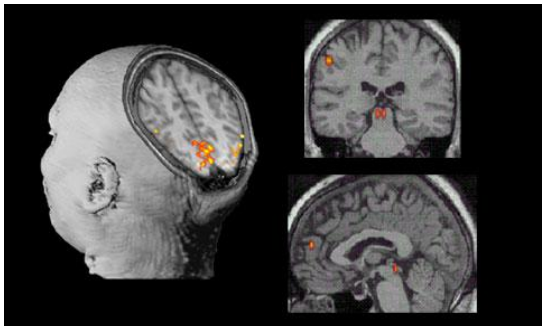
Out of Scope

- Putting EEG caps on intelligence analysts
- Models of *group* cognition (ICArUS focus is on *individual* brains/minds*)
- *Isolated* models of *single* brain/cognitive systems (ICArUS focus is on *integrated* models involving *multiple* systems)
- *Non*-biologically inspired approaches (i.e. classical AI, pure machine learning)
- Neurophysiological and behavioral data collection (ICArUS is principally a *modeling* effort!)
- Visual object recognition
- Natural Language Processing
- New hardware development
- Tools & widgets (for visualization, collaboration, assisted reasoning, etc)

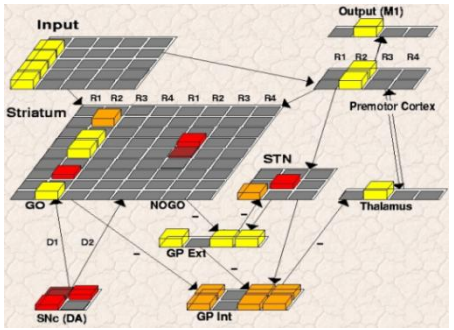
Why neuroscience?

The human brain is the only example of a general-purpose sensemaking system.

- **Recent advances in neuroscience research:**
  - new neural recording techniques
  - new data analysis methodologies
  - increased focus on computational modeling
- **Result:** Proliferation of computational models describing how brain accomplishes:
  - Learning and memory
  - Attention
  - Decision making
  - Goal-directed behavior
  - Sensory perception
  - Multisensory integration
  - And *many* etc's…



Combined structural & functional MRI



Computational neuroscience model

The scientific foundations are now sufficient to begin constructing an integrated neuro-cognitive model of human sensemaking

Modeling Approach

ICArUS seeks to develop ***computational cognitive neuroscience*** (CCN) models of human sensemaking

CCN is defined as an emerging discipline "at the intersection of neuroscience, cognitive psychology, and computational modeling, where neuroscience-based computational models are used to simulate and understand cognitive functions such as perception, attention, learning and memory, language, and [other] functions" -- http://www.ccnconference.org/

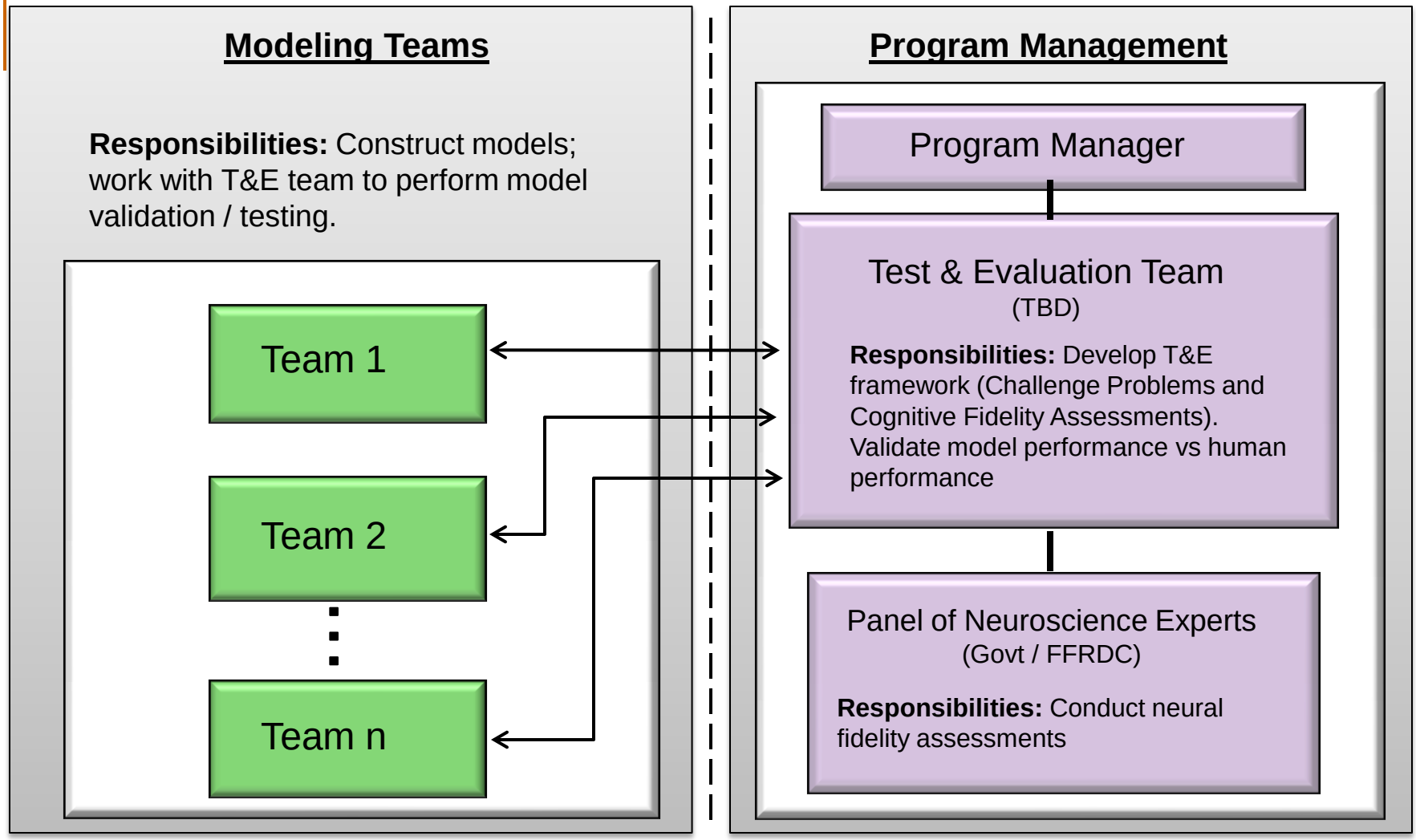
- Required neural structures will be specified in the BAA (discussed later)
- *Integration* of individual brain systems into a unified architecture is essential
- Exact level of biological detail will be decided by the modelers; extraneous details (e.g. 3D neuronal microstructure) will be discouraged
- Models should focus on 'higher-level' cognition (attention, learning & memory, decision making) as opposed to 'lower-level' perceptual processes (e.g., visual feature extraction)
- Level of biological detail may vary among modeled brain areas due to inconsistencies in our understanding of brain function

Teams are anticipated to be multidisciplinary, with collaboration among neuroscientists and theoreticians strongly encouraged

Required Neural Systems

Brain systems	Functions
Prefrontal Cortex	Attention, cognitive control, working memory, goal-oriented behavior, decision making
Parietal Cortex	Evidence integration, decision making, multimodal sensory representation, spatial reasoning, estimation of value and uncertainty
Medial Temporal Lobe, Hippocampus	Recognition and recall, declarative (episodic and semantic) memory, spatial cognition, relational processing, sequence learning
Basal Ganglia / Dopaminergic Systems	Reinforcement learning, reward signaling, slow statistical learning, action sequencing, procedural learning, decision making
Anterior Cingulate Cortex	Error signaling, cognitive control, conflict monitoring, decision making
Brainstem Neuromodulatory Systems	Attentional arousal, transition between exploitative and exploratory behavioral modes
Amygdala, Orbitofrontal Ctx, Limbic Structures	Emotional arousal, decision making, estimation of value

Program Structure

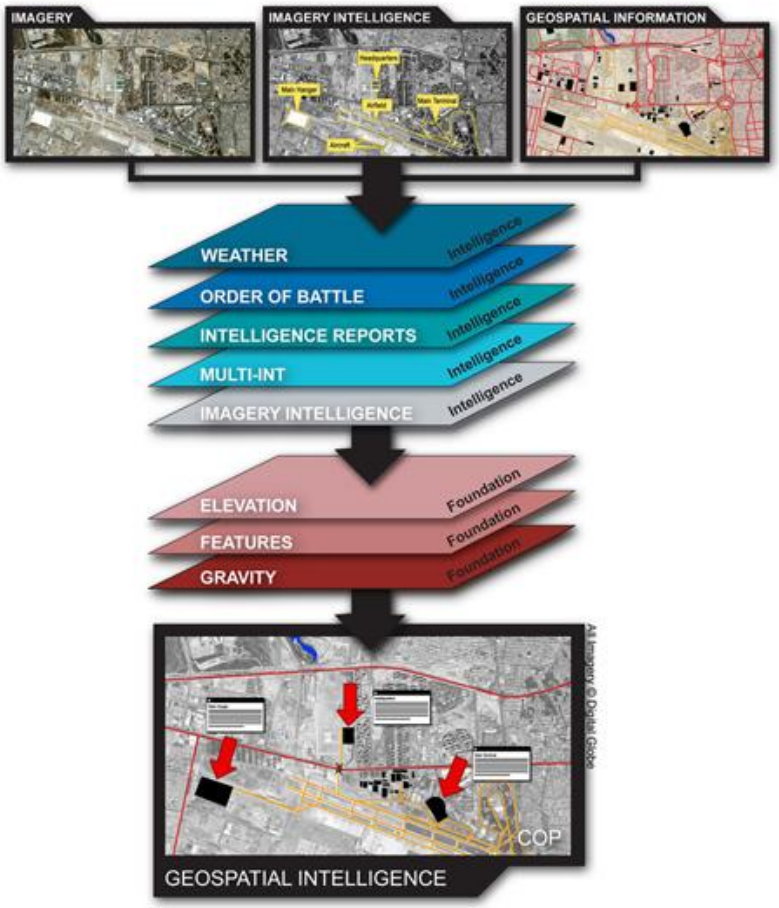


Challenge Problems

Purpose: Provide an integrated task environment / test framework for comparing model performance to human performance on end-to-end sensemaking tasks

- Challenge Problems will:
  - incorporate, in an integrated fashion, *all* major sensemaking processes within a single task framework
  - be developed by the independent Test & Evaluation Team in consultation with Modeling Teams and intelligence analysts
  - balance the need for operational relevance/realism and scientific rigor
- The following slides provide a *notional* description of the CP framework meant to help guide proposal development
- Details are subject to change
- Complete test specification & data sets will be developed/released *during* the course of the program

Challenge Problems



www.nga.mil/NGASiteContent/StaticFiles/OCR/nga0405.pdf

Challenge Problems will involve the analysis of simulated Geospatial Intelligence (GEOINT) data

GEOINT: "the exploitation and analysis of…geospatial information to describe, assess, and…depict physical features and geographically referenced activities on the earth. GEOINT consists of…imagery intelligence and geospatial information" (Title 10 U.S. Code 467).

Models will ***not*** be required to:
- Process raw imagery (pixels)
- Perform visual feature extraction / object recognition
- Process natural language

Challenge Problems

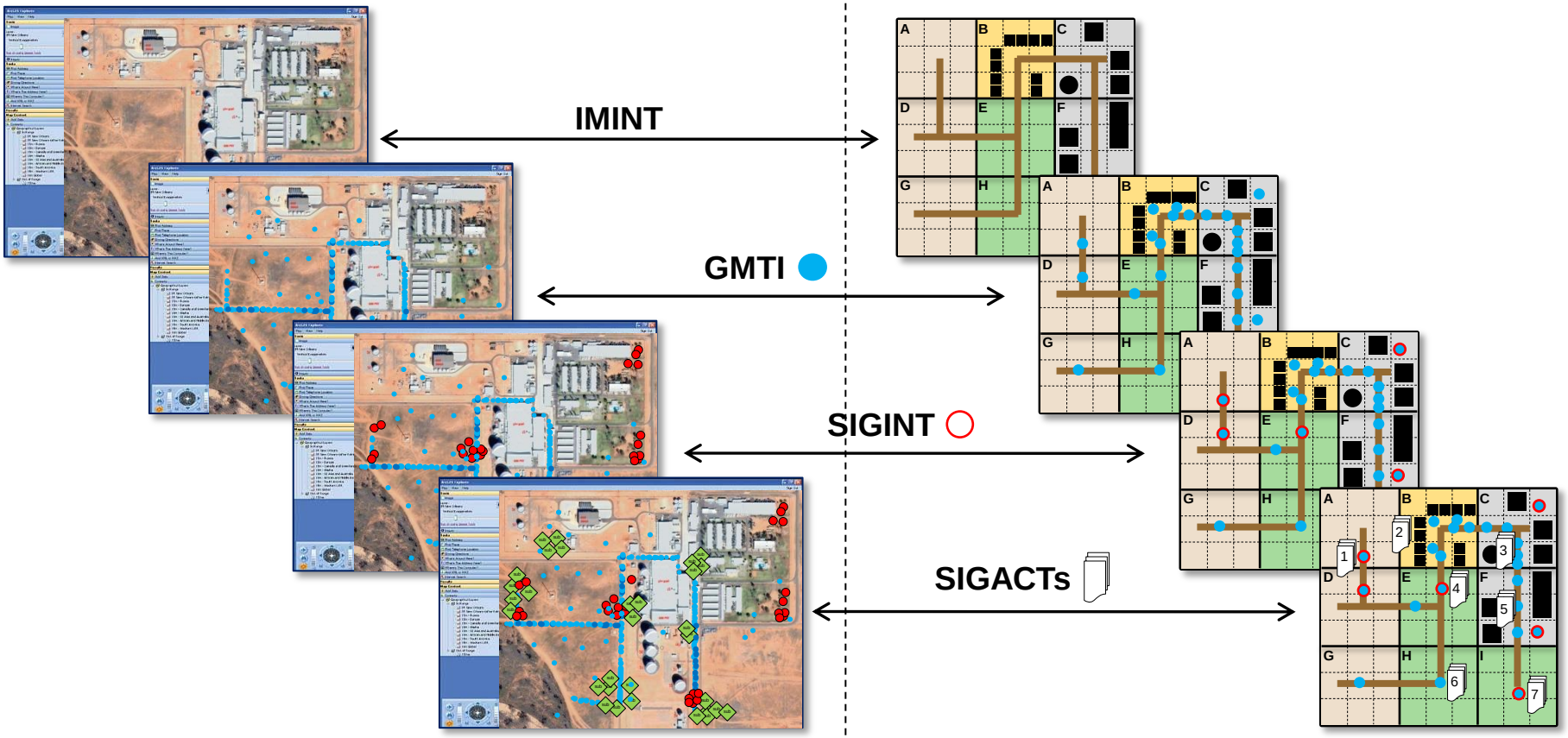
Additional Challenge Problem Characteristics

- Escalate in complexity as program progresses from Phase 1 → Phase 3
- Different for each Phase but similar in overall format (GEOINT)
- Involve “directed” sensemaking tasks (model must answer specific questions)
- Difficulty level is challenging for humans
- Inputs: multiple GEOINT ‘data layers’
  - each layer a separate info modality
  - multiple time points per layer (discrete time)
- Input format: multi-dimensional feature vector
- Questions are multiple choice
- Output format: confidence estimates for the different answer options, response selection

Challenge Problems: Inputs

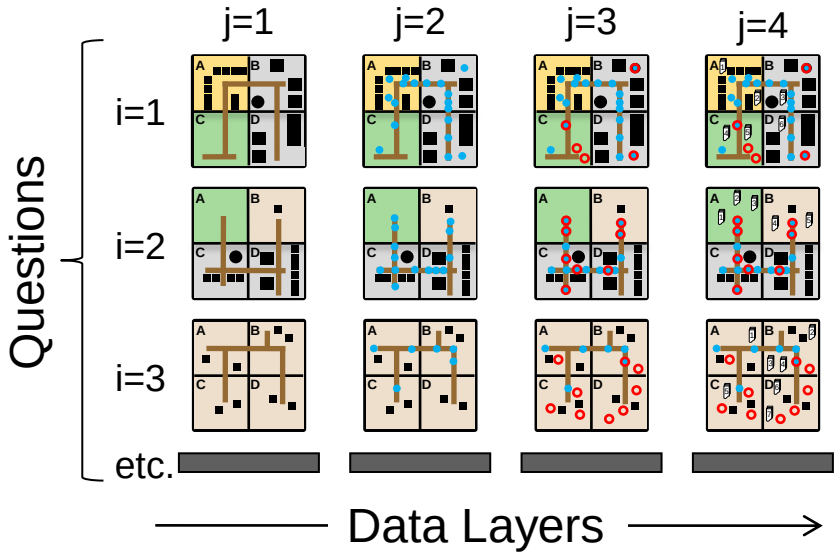
What an analyst sees
(layers of GEOINT data)

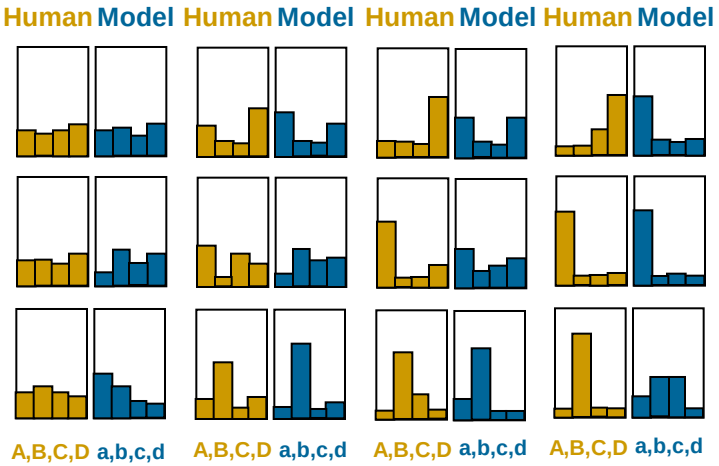
ICArUS inputs
(Multi-d feature vector / nXn grid)



Challenge Problems: Measuring Performance

Models will be compared with humans performing *same* Challenge Problem tasks





Humans and Models Runs*

- Inherently rich and extensible task framework
- Challenge Problems will be designed to control for humans' advantage in background knowledge

* *Bars show changing confidence levels for response alternatives A-D as more data layers are revealed*

Outline

- Program Overview
- Program Phases 
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Program Phases

- Distinguished principally by:
  - minimum required *capabilities of model*
    - types of frames learned/applied
    - search & decision processes
  - structure and complexity of *task environment*
    - role of *time*
    - probabilistic structure
  - *metrics & milestones* (to be discussed later)

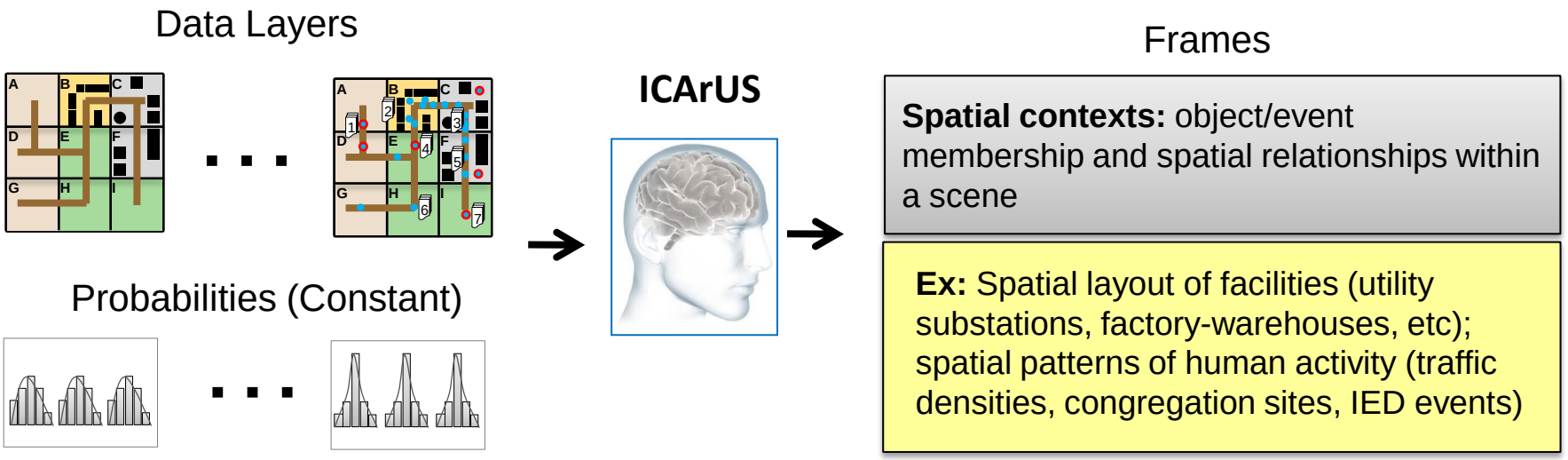
Teams will be encouraged/rewarded for aggressive approaches that exceed the minimum targets

Phase 1 (24 months)

Objective: Construct *integrated* neuro-computational model that captures *all* core sensemaking functions and that successfully performs the Phase 1 Challenge Problem

Minimum capabilities of model:

- Process *spatial* input data
- Operate in probabilistically *constant* environment
- Learn & apply *spatial context frames* to perform basic inferences
- Demonstrate *simple decision making* (e.g., select relevant data layer/source)

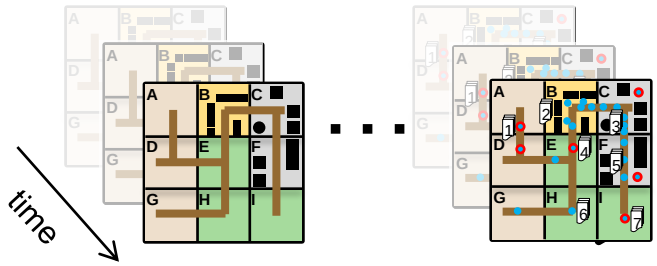


Phase 2 (18 months)

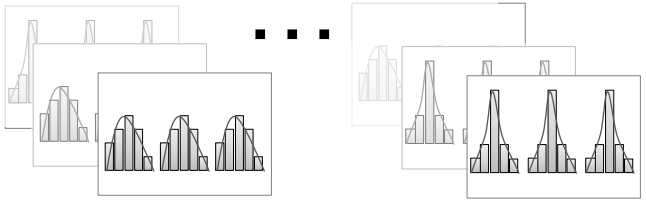
Objective: Expand functionality of model to include (at minimum) the ability to:

- Process *temporal* input data
- Operate in and adapt to probabilistically *changing* environment
- Learn & apply *event sequence frames* in conjunction with spatial context
- Demonstrate *complex* decision making (e.g., select relevant data layer / time slice)

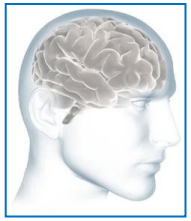
Data Layers



Probabilities (*Changing*)



ICArUS



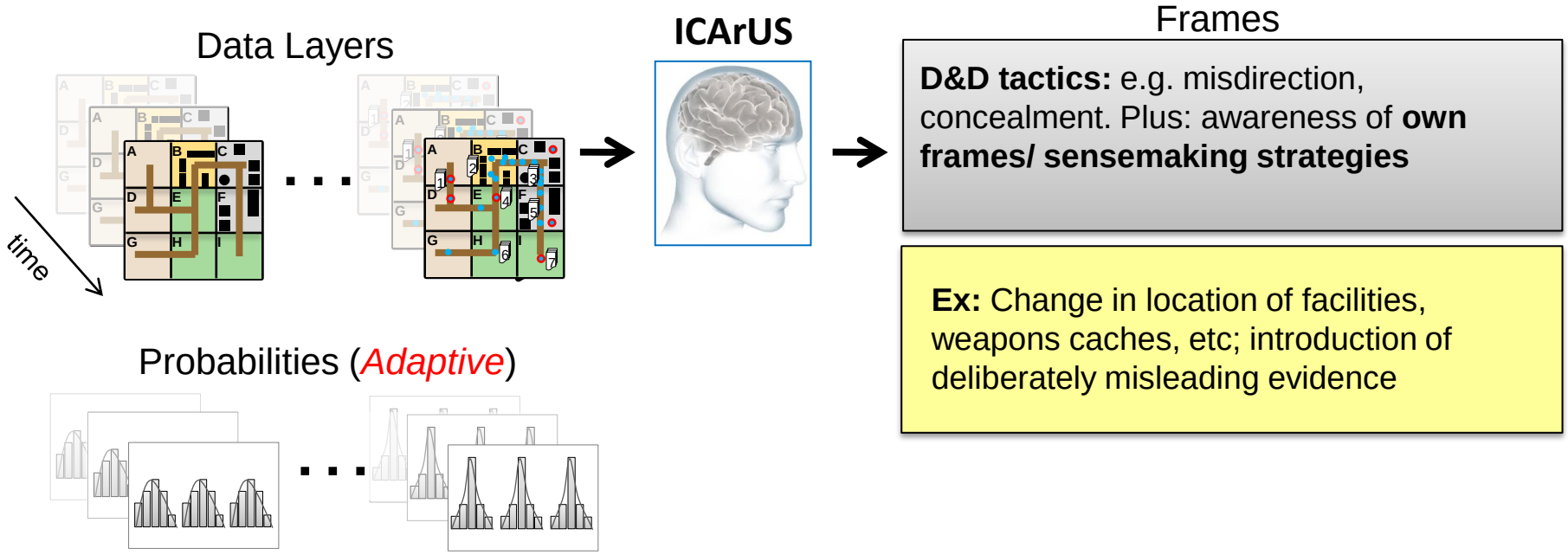
Frames

Event sequences: a.k.a. *scripts:* recurring actions and events ordered in time

Ex: vehicular traffic patterns; industrial activity (e.g. temporal patterns in factory emissions spectra, construction sequences), crowd movements, comms patterns

Phase 3 (18 months)

Objective: Extend the ability of the models to perform sensemaking under situations in which data (or the absence thereof) may be the result of *denial and deception*.



Three Phases

Phase	frames[1]	time[2]	statistics of environment
Phase 1	**spatial context**	no	constant
Phase 2	spatial context, **event sequences**	yes	changing
Phase 3	spatial context, event sequences, **denial & deception**	yes	changing-*adaptive*

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Metrics: Description

***Three* classes of metrics aimed at answering *two* different questions**

1) Neural Fidelity and 2) Cognitive Fidelity

How?

Do the models solve problems using the same processes and mechanisms that humans do?

neuro-fidelity (brain models)

yes/no

cognitive-fidelity (cognitive biases)

yes/no

qualitative

3) Comparative Performance

How well?

How do models compare with human performance on sensemaking Challenge Problems?

model performance (relative to *humans*)

% performance

quantitative

Metrics: Neural Fidelity

Purpose: Ensure that teams remain faithful to the ICArUS Program's objective of building *brain-based* cognitive models

Assessments will be made by PM Team with guidance from independent Panel of Experts (Govt, FFRDC). Judgments will be based on analysis of technical reports, model source code, and models' activation dynamics during task execution.

Criteria: For each of seven key brain systems…

- *Does model incorporate neurobiologically plausible components & design principles?*
- *Does the model maximally exploit existing knowledge of brain's functional architecture?*
- *Are model's internal dynamics during task execution consistent with the literature?*

Target Metrics: (fraction of key brain areas faithfully represented):
Phase 1: *3 of 7*
Phase 2: *5 of 7*
Phase 3: *7 of 7*

Metrics: Cognitive Fidelity

Purpose: Assess whether ICArUS models faithfully capture key biases and other cognitive idiosyncrasies known to impact (often detrimentally) human sensemaking

- Cognitive Fidelity Assessments will be:
  - conducted within same test environment as overall Challenge Problems
  - performed using *complete* integrated model
  - performed using consistent parameter settings (*no tweaking the knobs for each individual test!*)

Metrics: Cognitive Fidelity

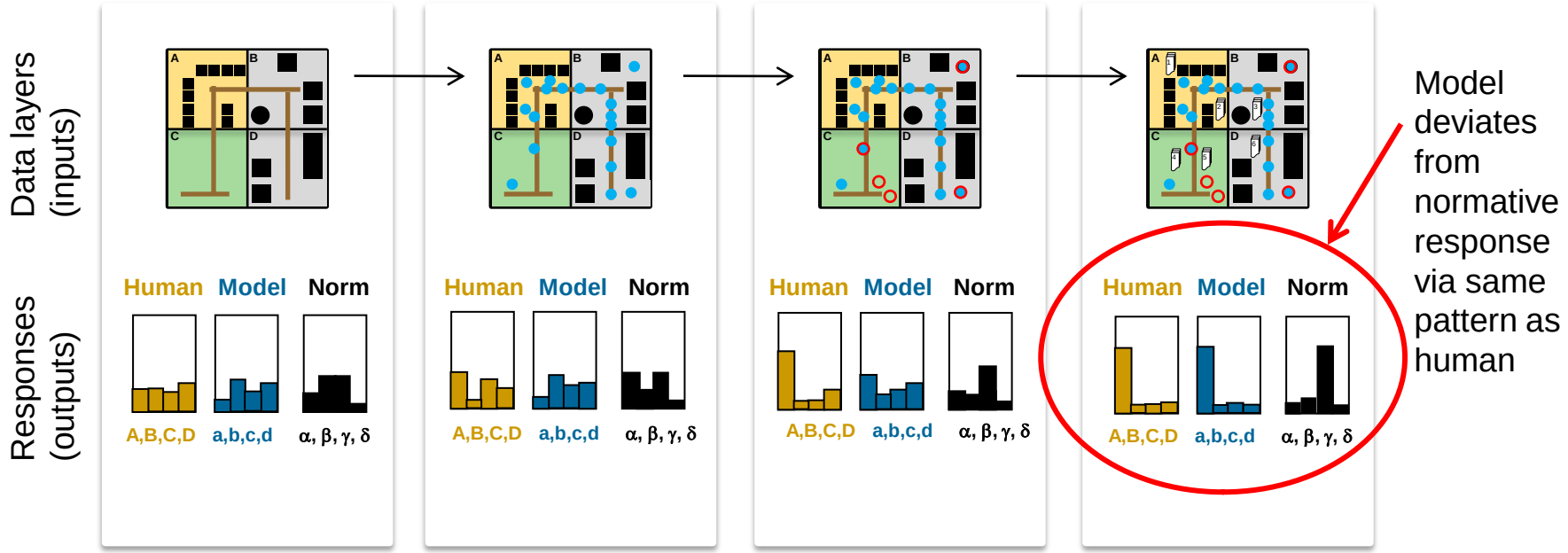
Examples of cognitive biases / idiosyncrasies of interest to ICArUS

- Confirmation bias
- Anchoring and adjustment
- Inattentional blindness
- Change blindness
- Satisfaction of search
- Representativeness
- Availability
- Vividness
- Probability matching
- Inductive biases (*learning to learn*)
- Overconfidence effect
- Over-reliance on evidence labeled ‘high value’ (e.g. “classified”)

Target Metrics: (fraction of key cognitive biases exhibited by model):
Phase 1: *2 of 4*
Phase 2: *5 of 8*
Phase 3: *8 of 12*

Metrics: Cognitive Fidelity

- Based on a 3-way comparison of model/human/normative responses.
- Key question*: Does model deviate from normative behavior in <u>same way</u> as human?*
- Separate assessments will be conducted for each bias of interest, with Pass/Fail result for each bias



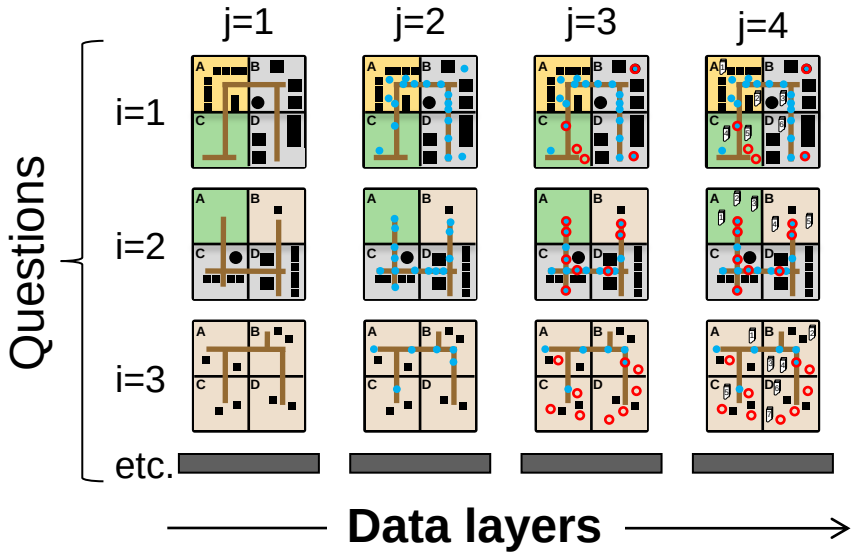
Metrics: Comparative Performance

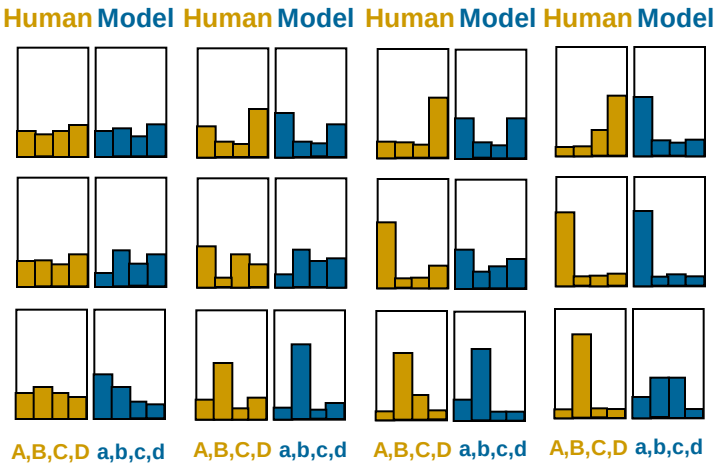
Purpose: Assess models' ability to *emulate* humans' overall performance on challenging sensemaking tasks.

Approach: Compare item-by-item response patterns of models to those of humans performing same Challenge Problem tasks. Measure the average divergence between model vs human responses.

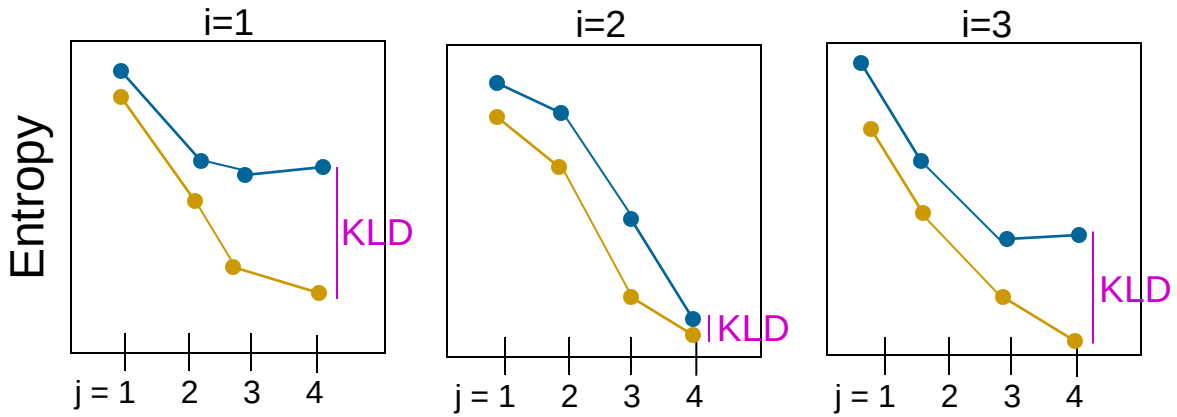
Goal is to match humans' response patterns – not just their scores.

Metrics: Comparative Performance

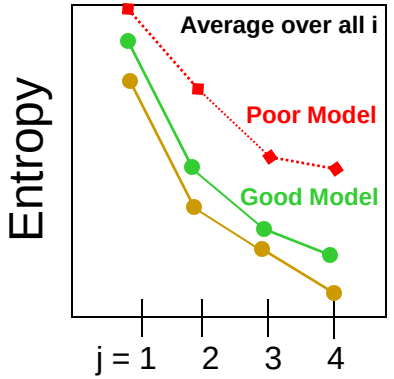




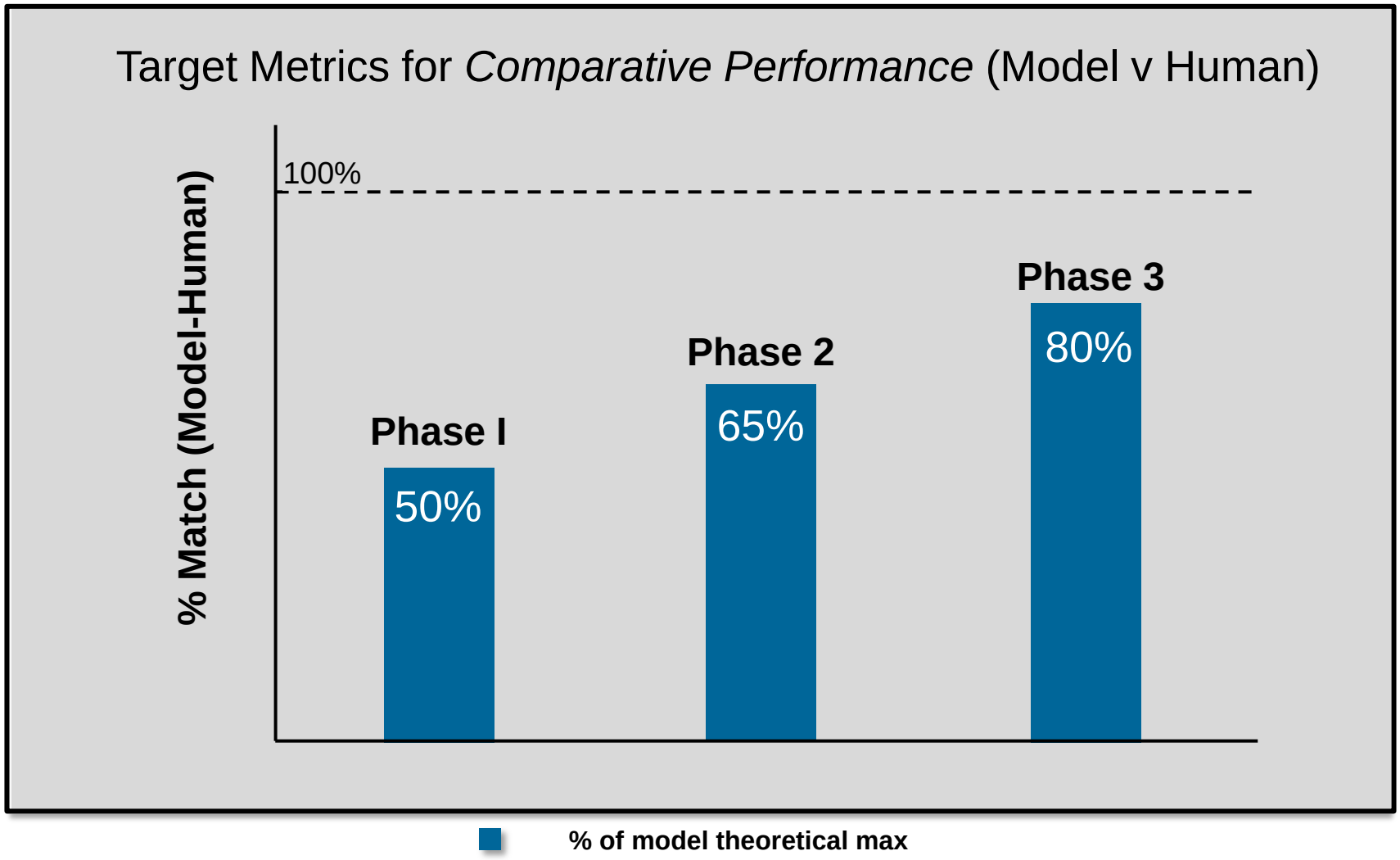
Human and Models



Base Entropy E, Cross Entropy E', KLD = E' - E



Metrics: Comparative Performance



Metrics: Summary

Test	Phase 1	Phase 2	Phase 3
Neural Fidelity (fraction of key brain areas faithfully represented)	3/7	5/7	7/7
Cognitive Fidelity (fraction of cognitive biases exhibited)	2/4	5/8	8/12
Comparative Performance (% of human performance level)	50%	65%	80%

Timeline

	Task	Phase 1				Phase 2			Phase 3		
		6 mo	12 mo	18 mo	24 mo	30 mo	36 mo	42 mo	30 mo	36 mo	42 mo
Modeling	Select/develop component models	■	■			■			■		
	Integrate models		■	■			■			■	
	Phase 1 Test & Eval				■						
	Phase 2 Test & Eval							■			
	Phase 3 Test & Eval										■
Test & Evaluation	Design Challenge Problem(s)	■	■			■			■		
	Collect Data		■	■		■	■		■	■	
	Administer Phase 1 tests				■						
	Administer Phase 2 tests							■			
	Administer Phase 3 tests										■

Technical Exchange Mtgs to be held at 6-month intervals. Technical/Financial status reports due monthly

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Award Plan

- 5-yr program
- Phase 1 – 24 months (12-month Base + 12 month Option)
- Phase 2 – 18 months (Option)
- Phase 3 – 18 months (TBD)

- Criteria for advancing to next phase: sufficient progress in current phase metrics
- Number of awards depends upon:
  - Quality of the proposals received
  - Availability of funds

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Eligibility

- All proposals must address *all* facets of the program
- Teaming/collaborations are *strongly* encouraged
  - Networking and team formation is responsibility of the proposers
- Foreign organizations and/or individuals may participate
  - Must comply with Non-Disclosure Agreements, Security Regulations, Export Control Laws, etc, as appropriate

Eligibility

The following are NOT eligible to submit proposals to this BAA or participate as team members under proposals submitted by eligible entities.

- Other Government Agencies
- Federally Funded Research and Development Centers (FFRDCs)
- University Affiliated Research Centers (UARCs)
- Any other similar type of organization that has a special relationship with the Government, that gives them access to privileged and/or proprietary information or access to Government equipment or real property

Eligibility

- Other Issues
  - OCI: http://www.iarpa.gov/IARPA_OCI_081809.pdf
    - Example: “any instance where an offeror, or any of its proposed subcontractor teammates, is providing either scientific, engineering and technical assistance (SETA) or technical consultation to IARPA.”
  - Publication is encouraged, but...
  - Performers should provide a pre-publication soft copy to:
    - IARPA ICArUS Program Manager
    - Contracting Officer’s Technical Representative

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Application Review Information

In descending order of importance

- Overall Scientific and Technical Merit
- Effectiveness of Proposed Work Pan
- Relevance to IARPA Mission and ICArUS Program Goals
- Relevant Experience and Expertise
- Cost Realism

Wrap-Up

- Thanks to:
  - Dr. Anthony Boemio
  - Mr. Kevin Burns
  - Dr. Peter Highnam
  - Rest of IARPA Front Office
  - Events Team

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(include IARPA-BAA-10-04 in the subject line)

Website: www.iarpa.gov

Questions?
Thank You!